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Advanced Planning and Scheduling system : An overview of gaps and potential sample solutions

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Abstract : This paper intends to take up an overview of gaps existing in Advanced Planning Scheduling system (APS). Even if APS system provide a number of solution approaches for several practical problems (inventory and global costs reduction, customer service level increase, pertinent decision making), improvement ways still emerge. Firstly, we have led a functional analysis, to identify some gaps about supply chain management activities (financial aspect and Engineering To Order concept). Then, we made a literature review to identify works have been done in these areas. This review allowed us to outline a second kind of weakness liked to the functional range of some modules too (demand forecasting, proposition of lots sizing, reactivity). So, gaps and potential solutions proposed in the scientist literature, are presented in this paper. We conclude by underlining another type of problem, concerning the management needed to install correctly an APS system.

Key Words : Advanced Planning and Scheduling system, Supply Chain Management, APS gaps, functional analysis.

1. Introduction

The supply chain management has gained importance, when competitiveness, responsiveness and customer satisfaction are key words of a successful management in a business area. According to a study, realised along a work of the project COPILOTES [1], three main factors could indeed achieve a global industrial improvement. First, the performance would depend on the implementation of an organisation and procedures; best-of-breed relations between partners would be the second facet then, information sharing along the supply chain, based on an integrated inter-organisational information system would favor the whole performance. After a short definition of the supply chain and its management parameters in section 2, we will focus our attention in section 3, on the system able to contribute to the second and moreover the third main point, site above: the APS systems, that sequence and optimize most of the enterprise's activities. Even if, such a system can be efficient to improve the management of a company from a supply chain point of view, it still charges gaps that are interesting to underline. So, in section 4, we have undertaken an analysis about APS functionalities to identify some lacks about supply chain management activities. It concerns, in particular the financial consideration and the Engineering To Order aspect. Then, in section 5, gaps and solutions proposed in literature for functional range of some activities are presented, like the speed of simulation, lots sizing propositions and forecasting performances.

2. Supply Chain and Advanced Planning

2.1 Supply Chain Concept

To introduce the concept of supply chain, we notice that there are two types of definition. Some of them insist on the "chain" aspect as follows : The set of entities, including suppliers, logistics services providers, manufacturers, distributors and resellers, through which material , products and information flow" [2], whereas others develop the 'network" point, as follows " A supply chain is a network of organization that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hand of the (ultimate) customer [4]. To sum up, we have chosen to refer to the very full definition given by Fenies and Gourgand [3] : "A supply Chain is an open space, crossed by three flows (financial, material and informational), composed by several actors (like suppliers, workshops, distributors, warehouses, wholesaler and retailers) that use a limited capital of resources (time, money, raw material or personnel) and coordinate their actions due to an integrated system, to improve their whole and individual performance."

To manage this Supply Chain, Stadtler [5] has identified several parameters that he presents through his "house of Supply Chain", like follow.

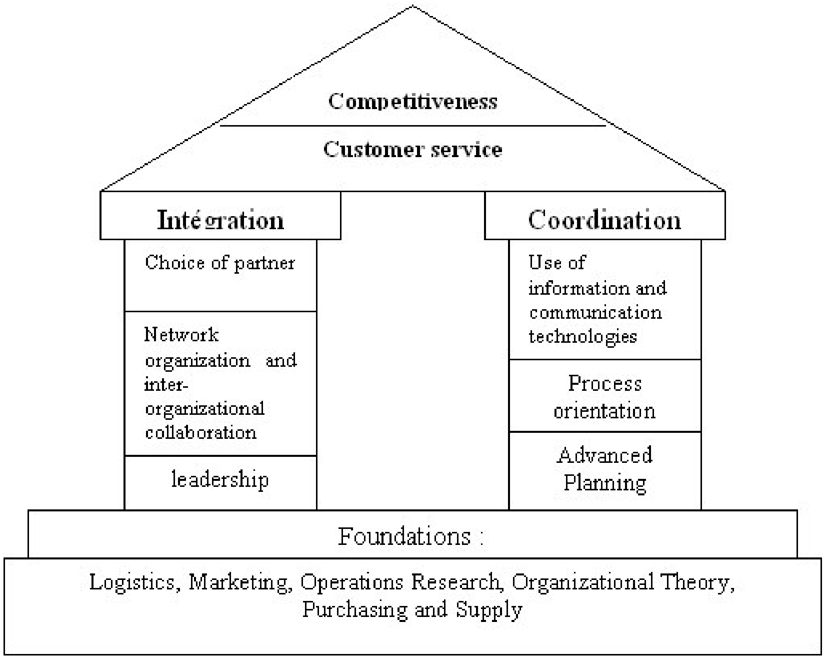

Figure 1. House of SCM [5]

According to him, the main goal is indeed the competitiveness of all links of the supply chain, and it is reached by a common strategy which the efficiency will be measured with the customer's satisfaction indicator. Two key concepts support the strategy : integration of all elements and coordination of flows.

To sum up Stadtler's idea, the integration is put across the choice of partners, an organization of a workspace and then, the selection of a leader. More specifically, all actors of the supply chain must have same goals, interests, final customers and some parameters (like a geographic nearness or financial position) that help to select ideal partners. Then, the creation of a common organization and workspace, helped by a zest of social science aim at sharing a same view but above all, favor a positive relationship between entities. Lastly, Stadtler conclude with the leader, distinguishable from the others by his technical or financial superiority, who supervises activities even if all actors stay independent.

The success of the second mainstay of Stadtler's theory, named "coordination", is determined by the use of information systems, orientation processes and advanced planning. The first element aim at synchronizing activities and flows by circulating information and then avoiding bullwhip effect, for example. The second point looks almost like the lean manufacturing because its goal is to suppress redundant actions along the Supply Chain. Then, the last attribute, on which we're going to focus our attention, is the advanced planning, strategic function in an unforeseeable environment. Before introducing tools able to manage the advanced planning (APS), it's interesting to recall the broad outlines of the concept.

2.2 Planning Concept

The planning's notion is closely linked with the integration between purchase, distribution and production services. As these activities are not dissociable, it's important to have a system that coordinate, in the same time, each planning due to the connection as follow:

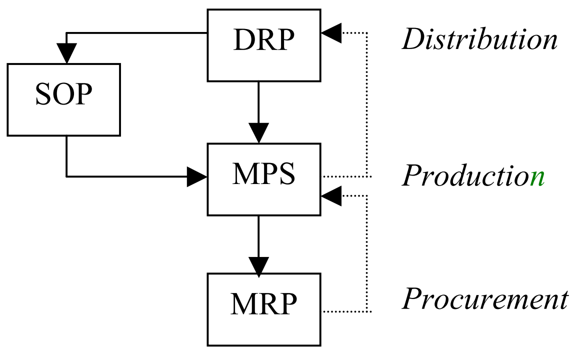

Figure 2. MRP II cycle [6]

Distribution Resource Planning identifies and sequences resources needed for products' distribution, from information like bills of distribution, customers' orders, forecasting, or inventory management. After assessing the situation, DRP forwards these raw data to the SOP (Sales and Operation Planning), charged to convert them into product lines. The MPS (Master Planning and Schedule) desagresses these families into item numbers; then the consistency of the product-mix, for instance, workshop's capability and commercial's demand can be checked. After the validation of both production and sales, the calculation of MRP follows for components to be produced and raw material to be purchased. The conclusion of this approach is a sequence of procurement, production, distribution and resources.

Now, we're going to present tools able to manage on computer this whole process in order to integer activities in the enterprise.

3. APS analysis

3.1 Presentation of APS

Since 1990, APS (Advanced Planning and Scheduling systems) appeared on the integrated system's market, to allow companies to take into account constraints of their supply chain and forecast consequences of different changes or decisions. But the business driver has been the enterprises' needs to integer their scheduling. Ended, even if production scheduling packages, working in finite capacity existed, they weren't coupled with others activities like distribution or transport, that had yet the same set of problems about sequences.

APICS Dictionary [7], defines APS system as follows: "APS describes any computer program that uses advanced mathematical algorithms or logic to perform optimization or simulation on finite capacity scheduling, sourcing, capital planning, forecasting, demand management, and others. These techniques simultaneously consider a range of constraints and business rules to provide real-time planning and scheduling, decision support, available-to-promise capabilities. APS often generates and evaluates multiple scenarios. Management then selects one scenario to use as the "official plan"; The five main components of APS systems are demand planning, production planning, production scheduling, distribution planning and transportation planning."

To conclude this full definition, we can sum up main the key success factors of APS :

- A real time overview along the supply chain
- A good decision-support package
- Ability to sequence in real time, taking into account constraints in finite capacity, events or changes.

An APS tool is modular as notified in the follow Fig. 3 and we can see for each module, which area of the supply chain management and which level is covered. This matrix is indeed built with planning process related to the buy, make move and sell business, that can be reviewed at the strategic, tactical and operational levels.

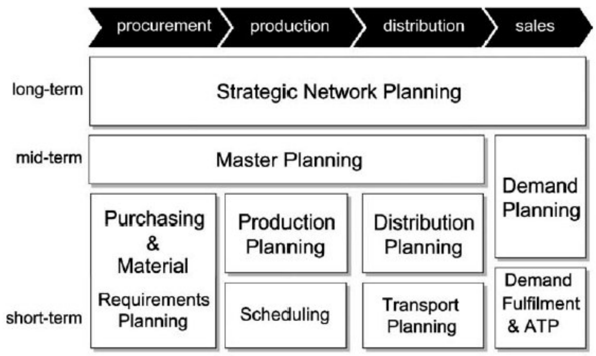

Figure 3. APS Matrix, [5]

For each module, a detailed presentation/definition is given by Stadtler [5].

3.2 APS advantages

Even if this paper aims at underlining main weakness of APS system, it's nevertheless interesting to remember shortly, the kind of improvement, one can expect with a APS implementation. We are used to distinguish quantifiable advantages and qualitative advantages.

Three main quantifiable benefits are commonly noticed : A reduction of inventory, an increase of customer service level and then, a reduction of whole costs. Inventories are reduced due to reliable forecasts that allow to reduce safety stocks and increase inventory turns. The customer service level is improved thanks to a reliable delivery lead time (modules ATP and CTP). The reduction of whole costs is generated, on the one hand, by an optimization of transport and distribution (vehicles load and routs), and on the other hand, by the reduction of redundant actions and work through the supply chain.

Two main qualitative benefits have been identified : relevant decisions and best availability of critical components. Decision making is more pertinent due to different simulations of scenarios and views of their impacts. Moreover, we can add that the overview through the supply chain is a valuable help to take good decisions. Lastly, forecasting and collaboration between supply chain's entities are a way to have right information about needs of components.

After seeing definition and advantages of the APS system, we tackle the APS' gaps aspect and more particularly, the two kinds of weakness detected.

4. APS gaps : supply chain management

4.1 Analysis

Our analysis bases its argument on the confrontation between two schemas : the reference model of APS (presented previously in section 3.1) and the model of Lambert [8] (here adapted, for more visibility).
This later model crosses business processes and typical functions. At each intersection, activities are defined. It gives an overview of all elements required for the implementation of supply chain management. Our goal has been to establish a link between these elements and APS's modules. Due to a game of color, we have superimposed them, in order to see areas covered by modules of an APS, as follows :

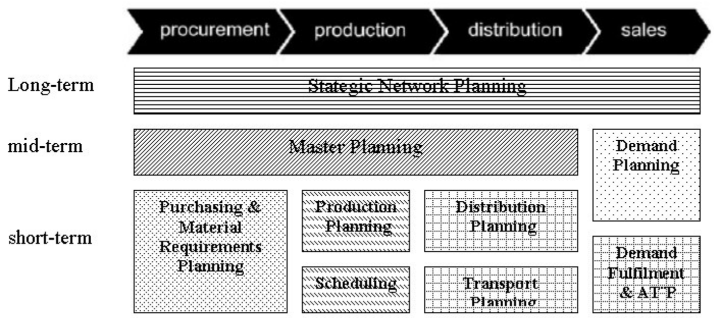

Figure 4. Confrontation of APS Modules and elements of the SCM

	Sales & Marketing	Technical	Logistics	Manufacturing	Purchasing	Finance& Accounting
CRM	Account management	Requirement Definition	Requirement Definition	Manufacturing Strategy	Sourcing Strategy	Customer Profitability
Customer Service Management	Account Administration	Technical Service	Performance Specification	Cordoned Execution	Priority Assessment	Cost to serve
Demand Management	Demand Planning	Process Requirements	Network Planning	Capability Planning	sourcing	Tradeoffs Analysis
Fulfilment	Special Orders	Environmental Requirements	Distribution Management	Plant Direct	Selected Suppliers	Distribution Cost
Manufacturing Flow Management	Packaging Specifications	Process Stability	Prioritization Criteria	Production Planning	Integrated Supply	Manufacturing Cost
Procurement	Order Booking	Material Specifications	Inbound Flow	Integrated Planning	Supplier Management	Material Cost
Product Development and Commercialization	Business Plan	Product Design	Movement Requirements	Process Specifications	Material Specifications	R&D cost

Figure 4. Confrontation of APS Modules and elements of the SCM

This simple work allows us to identify four distinct areas, presented in the Fig. 5 (original version [8]) .

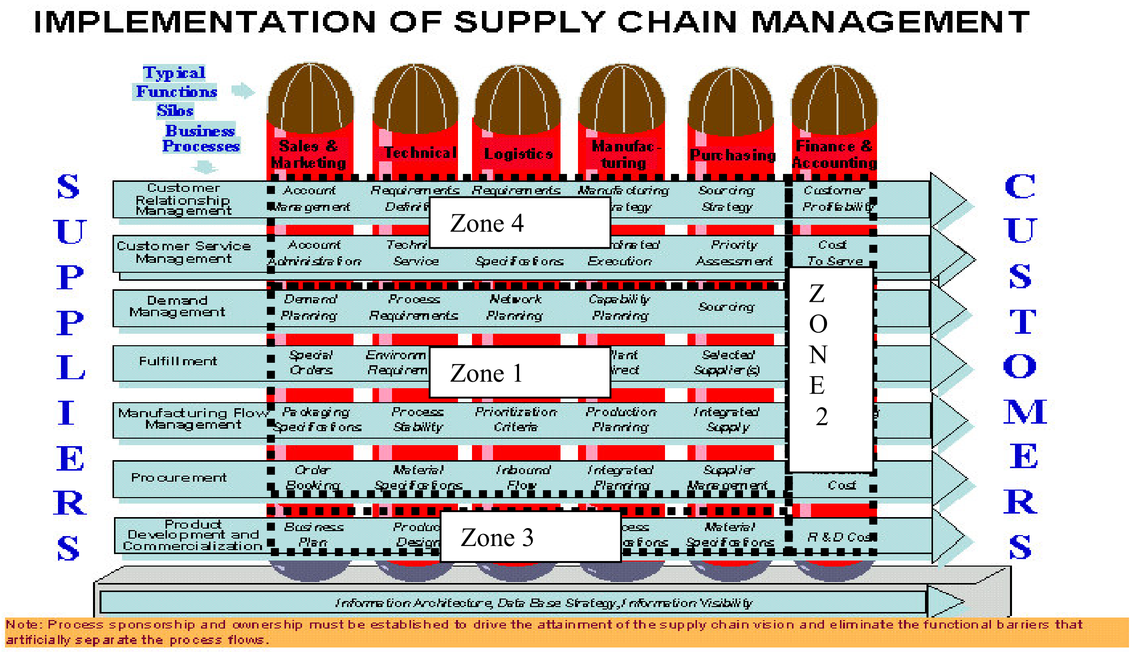

Figure.5 Implementation of supply chain management [8]

From the game of patterns, we notice, in the first zone, that modules favor the coordination between functions in the supply chain (quite all activities of a business process are underlined with the same pattern). From the zone 4, where only few activities are boxed, we can suppose that CRM (Customer Relationship Management) is not yet an area well covered by APS system. That's why, most editors used to develop specific and independent CRM tools. But, overall, two areas are really interesting for our study : zone 2 and zone 3.

Zone 2 concerns the financial function and we notice that this column has different colors for each business process. This observation drives us to a double conclusion. On the one hand, an APS system is able to manage financial flow since each box is colored. Moreover, most of objective functions are intended for maximizing the payoff and minimizing costs. So, the financial aspect is well taken into account. Nevertheless, on the other hand, there is not an integer management because of several colors : different modules manage different points of view of the financial flow. It is the reason why we can say that optimizations stay at a local level, without a whole conspectus.

Zone 3 concerns the business process linked to the development and commercialization of a new product, and more generally to the research and development. We notice that there is no color in this zone and this could mean that the advanced planning tools do not cover this whole part of process.

4.2 ETO gap

This short study allowed us to emerge kind of deficiencies of APS system, at the supply chain management level. These weakness have been already detected by Stadtler [5] about the first. According to him, "the master planning has been devised largely for make-and assemble-to-stock industries while engineer-to-order industries with only a few customers and low volume production quantities (like ship building and aircraft industries) are not adequately represented at the master planning level. Here, elements of a resource-constrained project scheduling type of model are still missing."

4.3 Financial gap

Badell and al [9] have worked on a solution that could be an answer toward this second problem. According to them, supply chain management can't take into account, in the same time, all flows, since none package is really able to couple financial and material aspects. Most of the time, these two subjects are supported by different environments. Thus, the decision making is quite incomplete. Consequently, the authors have decided to look into this problem, and more specifically on the links between financial and material areas. To them, finance should play the same role than material constraints, towards decisions in an enterprise. Their cash flow model with an advanced scheduling algorithm, based on linear programming can support the budget activity and is a real link with the APS, used by the company. After a summary of the principle governing this work, we're underlining main interests for a group.

The model needs to have several input data to run, such purchase or sell data, sources of funds, real and potential collections. These information are picked up in real-time in the system of the company, to inform the model about the financial situation along the supply chain. Six equations and several decision variables such liquidation, financial horizon, cash balance and credit allow to manage the cash flow.

- The first equation fixes a minimal financial stream not to be exceeded.
- The second equation takes into account all the data linked to the company's credits.

- The third evaluates the impacts of a sale of marketable values.
- The fourth assures the connection with the production since it lists the costs linked to the purchase of raw material and the forecast sales of finished products.
- The fifth gathers the conditions fixed by banks for a loan of cash.
- The last one allows to list the constraints concerning the payments of the suppliers or service providers.

From these information and constraints, the model tries to find the best timing of payment, investment in order to maximize profit from financial trade.

Thus, decisions are supported by the flow, and not by the management control anymore, less reactive. The model gives some results like a proposition of scheduling for financial operations and actions (suppliers payments or extinguishment of debt), in order to bring into balance the financial position. Several scenarios can be simulated, to know consequences of different alternatives. The model is also able to indicate the capacity of investment. To argue this idea, the authors have used a case study of a company who wanted to purchase new machines. Due to the model, it’s possible to know if this investment is rational, and moreover, some information are given about the way to proceed. Indeed, the system has taken into account several parameters like interest rate or discounts, and proposes the optimal reimbursement date.

This model has the advantage of being able to connect itself to an APS, at two levels : from purchasing of raw material and from sales of finished goods, in order to have data of the advanced planning system. The APS gives to the model some constraints and the planner can add his own constraints. With these elements, the budget model is created and several simulations are done to test different solutions.

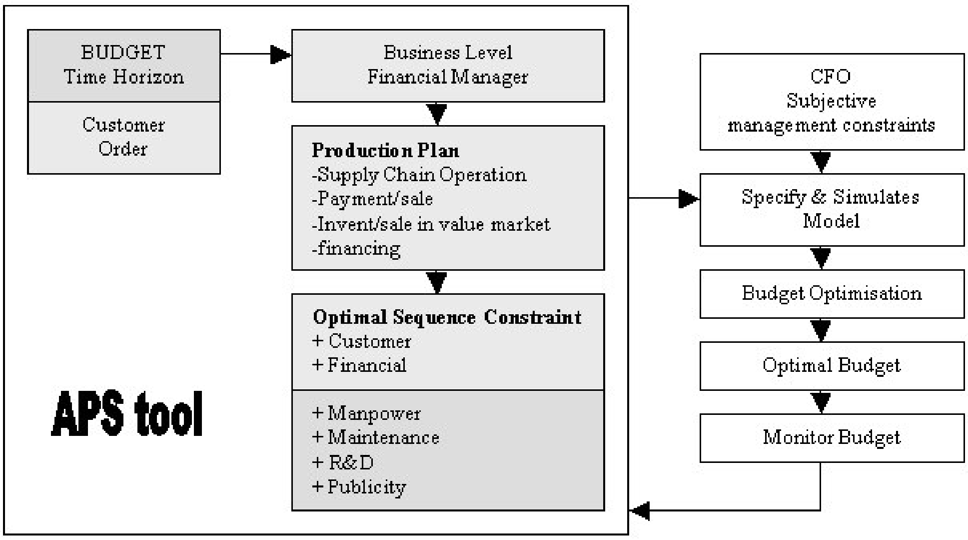

Figure.6 Financial Model [9]

Lastly, due to the link between the APS and the financial model, the model can consider the production scheduling with a financial point of view and validate it if there is no cash out.

To conclude, we can underline that, with this model, the planner has all the information to help efficiently the production and then, a good decision making. A real interaction would exists between financial flow and the others (information and material).

5. APS gap : functionality

We've just seen deficiencies of advanced planning tools concerning the supply chain management. As we said before, there is an other kind of problem. Some functions are quite weak : reactivity of production scheduling, optimization of lots-sizing, and demand forecasting. Lets explain this, more precisely.

5.1 Planning and reactivity

Reactivity is required for the industrial performance. An advanced planning tool should be able to detect events in real time, and react quickly with an other solution, to reduce harmful consequences. Obviously, the key point is the speed of the reaction. Indeed, if the time to simulate several scenarios of solution exceeds few hours, the situation in the workshop has changed and consequently, the proposition is already outdated. It's about this problematic, that Charpentier and Thomas [10] have decided to work. It's the reason why we can quote their works. According to them, when the situation is complex, with a lot of variables, most of programs are too heavy to be reactive. Many calculations taking a long time are required. That is why, they developed a model that reduce time to simulate with a simplification of the problem. Also, the decision making is quickest.

This model is based on the simplification of planning sheets and considers only essential work centers, named bottlenecks. The others are gathered as follows :

Pre-block aggregated → **Bottleneck** → **Post-block aggregated**

Number of elements, data, connections and parameters are significantly reduced, and it's the reason why calculations for scheduling are quicker : we obtain a reduced model. Moreover, two indicators are used to evaluate the reduction of complexity and the reduction of time to simulate.
To keep results with sufficient quality, it's essential to identify critical centers. We distinguish three kind of them :

- Conjectural bottlenecks, which are saturated by the initial scheduling
- Structural bottlenecks, which are used to be saturated most of the time
- Synchronization work center, essential for the synchronization of production orders.

All the others are gathered upstream and downstream.

Synchronization work center have been detected by an algorithm that identify resources which are not a bottleneck but by which the maximum of production orders using not bottleneck in their planning sheet. These selected work centers will be strategic points for the scheduling.

With a case study, Charpentier and Thomas have checked their model and particularly, two main points : the efficiency of their reduction, that they check with the two indicators we've talked before, and the quality of their results that they compare with issues obtained with a whole model. Results are convincing and comparable with a complete model. Nevertheless, when there are an important number of production orders to schedule, after an event, reduced model is quicker than a complete model, but solutions are not as good as before.

As a conclusion, we underline the interesting aspect of this reduction at operational level, in order to have hurry simulations for the workshop.

5.2 Demand Forecasting

As we know, the precision of forecasting is an essential parameter to have a good process of decision making, due to the use of the module "Planning and forecasting Demand, in an advanced planning tool. This forecasting is used to build a strategic plan, on the long term. As there are several forecasting models, it's important to choose the most appropriate program, to avoid to make errors in decisions and above all to change often the organization of the enterprise.

According to Stadtler [5], models are sometimes not enough sophisticated, to give right demand forecasts. In front of this problematic, we can quote the works of Louis, Cox, Douglas and Popken [11], who proposed a new model especially for new products which have no historic data. For instance, mobile telecommunications carrier are concerned and they can derive benefits from the hybrid system, using the Hidden Markov Model (HMM) and a classification tree algorithm to forecast the customers' behavior.

The first step of the work is to use the HMM approach, to obtain first forecasts, from few data like products, customers. This method is specially adapted for system which have only incomplete data. The originality of the concept is at the second level, since it combines several forecasts, with the classification tree algorithm, in order to improve results.

Here are successive steps to initialize the HMM concept.

1. Identify the core products to study. Indeed, it's not useful to waste time for products, that can be forecasted from others products.
2. For the main products, identify all possible combinations and make all calculation of appearance frequency. Eliminate rarest combinations.
3. Use a cross breeding program to increase information.
4. Calculation of forecasts for products outside of the core products.
5. Check results from an historic data to valid.

After this initial process, we apply the HMM principle, as follow :
Two process are considered : the first one is a real process with real data taken from historic (Y) and the second is a hidden chain of Markov (X) (Hidden = no observable). The goal is to forecast as right as possible the realization of X from realization of Y. From an input data, there are several possible outputs, with different probabilities.
In concrete terms, Y represents the sample of customers that have bought options in mobile telephony. The goal is to know the probability of occurrence that a customer having few options will choose such and such new products.
Using different techniques like HMM_Flat, HMM_Best, HMM_Small and ACHAT_Small, we obtain several scenarios which performance changes for each mix product.

An hybrid forecasting technique of customers' behavior is now created by mixing these results. According to the authors, each technique is a variable with a value for each customer. This value is the probability given by the method, that a customer follows one of the combinations. The model achieves with a classification tree that cross values of variables.

Tests made on samples proved that the reliability is improved for most of combinations when several techniques are used, particularly when historic data aren't numerous.

5.3 Propositions of lot sizing

According to Tempeilmeier [12], "the most disappointing characteristic of APS is that lot sizing issues are still handled in an unsatisfactory way". "Indeed, while it is known that standard general purpose MIP algorithms based on standard modeling approach will not able to solve even small lot sizing problem instance, even if, the planner is offered the opportunity to include fixed setup cost in the master planning". This opinion is shared by Stadtler [5], who adds that this weakness is prejudicial for the industry process, where setups are strategic elements. Models are too simplistic that is why they can not solve complex problems and solutions found are not efficient enough.

In front of this gap, Berretta and Rodriges [13], have developed an heuristic that could be a solution to this APS's gaps since it able to solve complex lots sizing problems for the planning. Their model takes into account, for all levels of the bill of material, cost, inventory constraints in order to suggest the optimal lots sizing. The aim is to minimize setup time and setup costs for all components of the final product.
Their approach, named "memetic algorithm", is a mix between the local research technique of Franca [14] (see Figure 5) and the genetic algorithm principle.

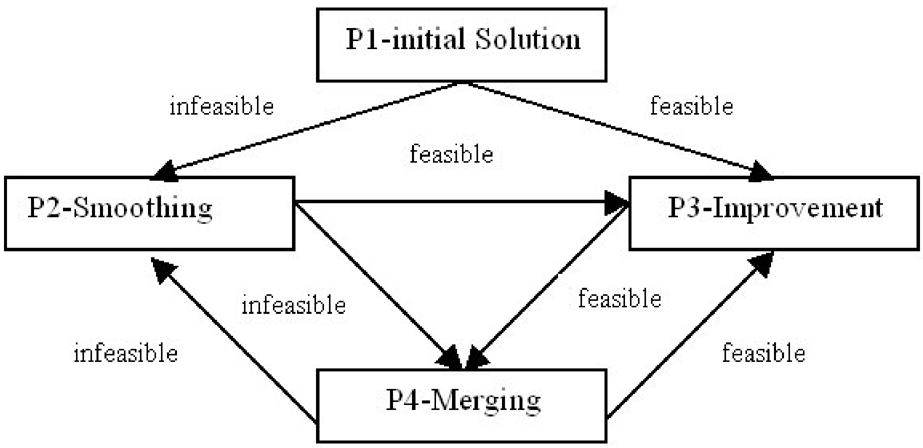

Figure.7 Model of Franca [14]

The procedure is initialized with the algorithm of Wagner and Within [15], in order to identify an initial solution, only for the final product without taking account capacity constraints. Then, with iterations, a first solution is found for each component, without being concerned with capacity constraints. This first step is exactly the same of procedure P1 in the algorithm of Franca. The second step is like P2 and the goal consists in smoothing the initial solution to obtain a feasible result. In fact, smoothing a solution consists in moving overloads through different periods to suppress them, and to minimize costs in the same time. So, several answers are proposed. Then, one of the specificity of genetic algorithms is used : crossing of solutions. Indeed, they are mixed, with respect of the order of the bill of material (from final product to components) and inventory constraints. News solutions are thus generated and the most efficient are kept and crossed again, during N iterations. The notion of mutation appears too. A random function is introduced to change solutions (move load in other periods). Only better answers (evaluated due to the setup time and setup costs linked) are kept. At the end, they obtain a core of propositions, that are injected in the system, to increase diversity and to avoid to stay in an local optimum. Either a time limit is chosen to finish the procedure, or it is fixed by a minimum threshold of quality. Nevertheless, because of the nature of the approach (heuristic), let's remember that there is no guaranties of answer.

In term of results, several tests and comparisons have been done by the authors, on two main criteria : On the one hand, ability to find a feasible solution (respect load and capacity) and in the other hand, the success of the optimization (lots sizing minimizing costs set up). Results are convincing since, for 71% of case, a feasible answer has been found, and the rest (29%), the overload capacity was only 2.1% (low rate). Moreover, the solution was efficient since the difference with the optimal solution known (obtained after a long time) was only 0.2% whereas the one's of Franca was more than 2.1%. Lastly, method of Tempelmeier found less often feasible solutions.

5.4 Remarks

A remark concerning the behavior of persons in charge of the implementation can be added towards these systems. Often, they are not enough well trained and they can lessen APS's abilities.Indeed, a study lead by Anastasia and al [16] shows that there are two types of errors. Firstly, most of the time, people want to have quick results, and so, they are inclined to simplify their problems and constraints. Since it's not easy to complete the model after, solutions found with the advanced tool aren't appropriated at the reality.

The second error consists in choosing progressive implementation for APS system. Indeed, most of people prefer to operate progressively and decide to implement manufacturing plant after manufacturing plant, whereas they should do all in the same time, to keep a coherent use. We notice a lack of coordination and thus, the capability of the system is reduced.

6. Conclusion

As the discussion has shown, APS provide a number of solution approaches for several practical problems. For example, an advanced planning system allow to reduce inventory, and global costs, increase customer service level but equally, allow to take pertinent decisions and have an overview about needs in critical components.

However, there are still several areas that need to be improved and this document aims at building an inventory of inconveniences and market prospects about advanced Planning systems. We have seen that, there are two main types of weakness, gaps linked with supply chain management and gaps linked with functional range of some activities in APS system. For most of them, we have found in the scientific literature, some solutions that could be solve or at least improve weakness previously identified.

To conclude this paper, we can identify another perspective. After detecting some of gaps in the advanced planning system, it could be interesting to evaluate the real added value generated by their solve in the industry area. Indeed, the knowledge of real needs and uses' companies could help us to determinate priorities in the resolution of gaps detected previously.

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